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Study on the Influence of Nonlinear Effect on Pulse Trapping in Photonic Crystal Fiber

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Abstract: Based on the nonlinear Schrödinger equations which can satisfy the optical pulse's transmission in photonic crystal fiber, it is numerically simulated the pulse t rapping courses between the pump pulse in negative dispersion region and the signal pulse in positive dispersion region using step by step Fourier method, and the effect the nonlinear coefficient to the trapping course. The result shows if the nonlinear coefficient is small, the pulse trapping can't realize. Conversely, if the nonlinear coefficient increases, the cross phase modulation between the two pulses is enhanced and the frequency shifts are intensified too. When the group velocity is matched, the pulse trapping is realized. And the degree of trapping is strength accompany with the nonlinear coefficient increasing.

Introduction

In 1989, the phenomenon of pulse self-trapping was observed first time [1]. It attracts people's attentions because this phenomenon can be applied to the hypervelocity optical switch which is the key technology in hypervelocity optical communication [2]. And the same time, as reach focus in recent years, photonic crystal fiber (PCF) is found to have many special properties, such as endless single mode property, flexible controllable dispersion property, the nonlinear property which can be enhanced and so on[3-5]. The usage of PCF in generation super continuum, dispersion compensation, pulse sequence and wavelength shift is widely researched and the good effects have been obtained in a few years [6-7]. But the pulse trapping in PCF is less studied. So the pulse trapping in PCF is numerically simulated and the nonlinear coefficient of PCF influences to pulse trapping is mainly discussed in this paper.

1Theory model

Pulse trapping is that the two pulses can overcome the walk off effect which leaded by their different initial group velocities and propagates at same group velocities ultimately in the fiber because of the function self phase modulation, cross phase modulation and other nonlinear effect In this paper, the pulse trapping of signal pulse and pump pulse is analyzed based on their propagation in PCF. The two pulses propagation in PCF is satisfied the nonlinear Schrödinger equations:

$$\frac{\partial A_s}{\partial z}+d\frac{\partial A_S}{\partial T}+\sum_{n=2}\beta_{ns}\frac{i^{n-1}}{n!}\frac{\partial^n A_s}{\partial T^n}=i\gamma_s[|A_s|^2A_s+2|A_p|^2A_S+\frac{i}{\omega_0}\frac{\partial}{\partial T}|A_s|^2A_s-T_RA_s\frac{\partial|A_s|^2}{\partial T}] \quad (1)$$

$$\frac{\partial A_p}{\partial z}+\sum_{n=2}\beta_{np}\frac{i^{n-1}}{n!}\frac{\partial^n A_p}{\partial T^n}=i\gamma_p[|A_p|^2A_p+2|A_s|^2A_p+\frac{i}{\omega_0}\frac{\partial}{\partial T}|A_p|^2A_p-T_RA_p\frac{\partial|A_p|^2}{\partial T}] \quad (2)$$

Where A_S and A_p are the amplitudes of signal pulse and pump pulse, $T(T=t\text{-}z/v_{gp})$is the time in delay system, $d=1/v_{gs}\text{-}1/v_{gp}$ is group velocity mismatch parameters, β_{sn} and β_{pn} are the n-order dispersion coefficient when signal pulse and pump pulse propagate in PCF, $\gamma=\frac{n_2w_0}{cA_{eff}}$ is nonlinear coefficient, T_R is Raman scattering coefficient.

Because the equations (1)and (2) haven't analytical solution in common, the signal and pump 's propagation in PCF are numerically simulated by computer using step by step Fourier method.

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The signal pulse and pump pulse input waveforms are

$$A_s(0,T) = \sqrt{P_s}\,\sec h\left(\frac{T-T_d}{T_s}\right) \tag{3}$$

$$A_p(0,T) = \sqrt{P_p}\,\sec h\left(\frac{T}{T_p}\right) \tag{4}$$

Where $P_s = A_{s0}^2$ and $P_p = A_{p0}^2$ are the peak power of signal and pump pulse. $T_S$andT_p are signal and pump pulse half width, and T_d is delay time between two pulses when they input.

Numerical simulation results and analyses

Under the hypothesis that the zero dispersion wavelength of PCF is 760nm, the central wavelength of pump pulse is selected in negative dispersion region and the signal pulse is in positive region to realize the pulse trapping, and the wavelength is near the zero dispersion wavelength. The other parameters are T_R=5fs, T_d=50fs, P_S=1W,P_P=50W,β_{s2}=-1.6257×10^{-5}fs^2/nm,β_{s3}=2.1089×10^{-5}fs^3/nm, β_{s4}=-2.2919×10^{-5}fs^4/nm,β_{p2}=-6.6715×10^{-5}fs^2/nm, β_{p3}=2.3233×10^{-5}fs^3/nm,β_{s4}=1.0307×10^{-5}fs^4/nm

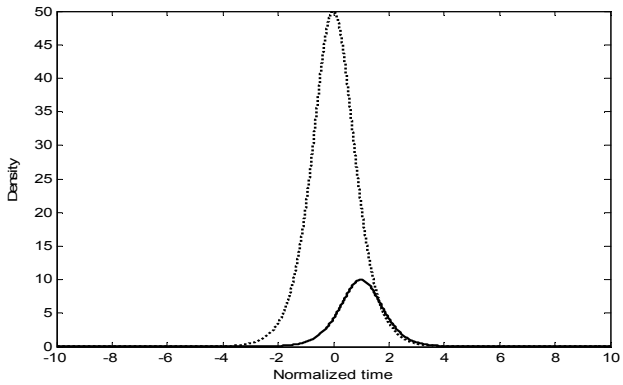

Fig.1 Input signal pulse (solid line) and pump pulse (dash line) shapes

Fig.1 shows the wave shapes of input signal pulse and pump pulse. It's worth to explain that to observe signal pulse better, it is amplified 10 times when it is mapped. And it is suitable to the other pulse wave shapes figures.

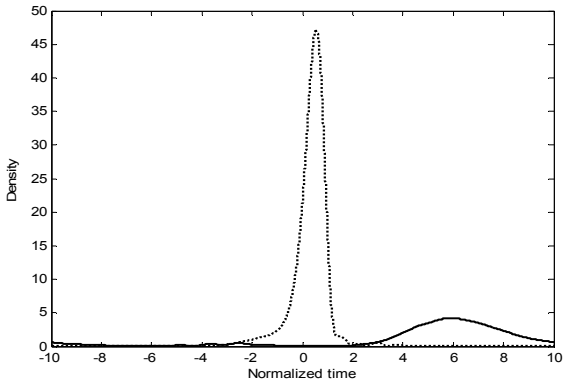

Fig.2a Pulse shapes with γ_p=20.04W^{-1}km^{-1}and γ_s= 28.012W^{-1}km^{-1}

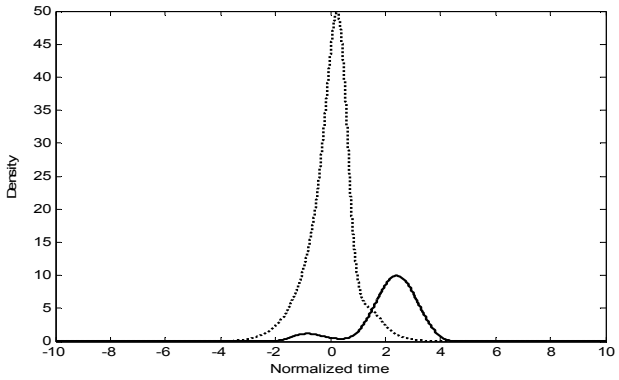

Fig.2b Pulse shapes with γ_p=50.01$W^{-1}km^{-1}$and γ_s=70.3 $W^{-1}km^{-1}$

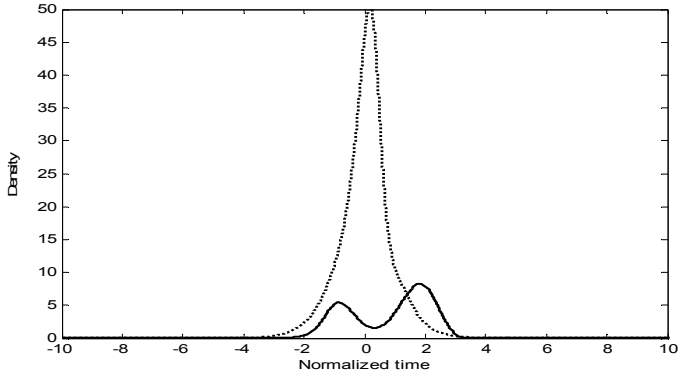

Fig.2c Pulse shapes withγ_p=100.2$W^{-1}km^{-1}$and γ_s=140.6 $W^{-1}km^{-1}$

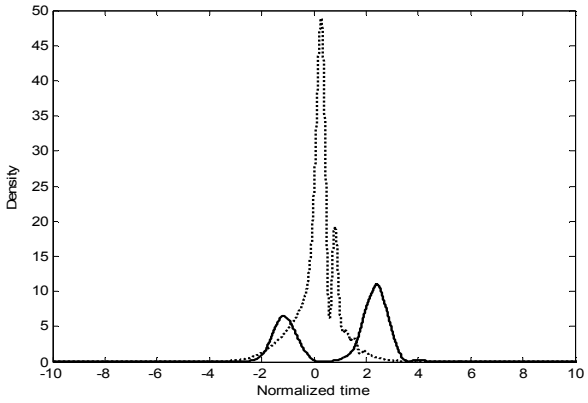

Fig.2d Pulse shapes with γ_p=200.4 $W^{-1}km^{-1}$and γ_s=281.2 $W^{-1}km^{-1}$

Fig.2 Output signal pulse (solid line) and pump pulse (dash line) shapes with different nonlinear coefficient

Fig.2 series show the output signal pulse and pump pulse shapes with increasing respective nonlinear coefficient and the same propagation distance.

Fig.2a shows that the pulse trapping can not be realized after a propagation distance when the nonlinear coefficients of two pulses in PCF are small. The first cause is the input time of signal pulse delays the pump and its group velocity is slower than the pump's. These lead to the collision time between two pulses reduce. Moreover, the small nonlinear coefficients mean the nonlinear effects including cross phase modulation (XPM) are weak. Although their frequency shift in respective region are occurs which can lead to the two group velocities reduce, the signal pulse don't catch up with the pump pulse because the pump reducing degree is smaller than the signal that means the signal pulse group velocity always is slower than pump, The two pulse depart from each other more and more.

From Fig.2b to Fig.2d, it can be observed that with the nonlinear coefficients increasing, the signal pulse wave occurs splitting and some of them propagate with the pump pulse. The pulse trapping is realized. The reason can be explained is the XPM which pump pulse act on signal pulse front edge is strength with the nonlinear coefficients increasing, and because of signal pulse in positive dispersion region the nonlinear effect leads to the blue-shift occur and these shift frequency components propagates slower ,so the group velocity of signal pulse reduced. Meanwhile, to pump pulse it is the red-shift and these red-shift components propagates slower in negative region. So the group velocity of signal pulse reduced Moreover, the negative chirp leaded by negative dispersion can partly offset partly the positive chirp leaded by nonlinear chirp, so the pump pulse is compressed. This can make the degree of red-shift and the group velocity decreasing of pump pulse more obvious. When the two group velocities are matched, the pulse trapping is realized.

Otherwise, the different degree of pulse trapping from Fig2c to Fig2d is explained that with the XPM to signal pulse front edge increasing, the splitting of wave shape is larger. The front edge of signal pulse which exceeds the pump pulse are increase, while the back edge is trapped by pump pulse. So the nonlinear coefficient is larger, the more high degree of trapping is.

Conclusions

Through the numerical simulation to the pump pulse and signal pulse by FFT, it studies the nonlinear coefficient of PCF effect to pulse trapping. The result discovers: Under the special conditions, the pulse trapping can be realized with the nonlinear coefficient increasing and the degree of trapping is also improved.

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